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CTS ATTENUATION AND CROSS POLARIZATION MEASUREMENTS AT 11.7 GHz

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16. Abstract

Using the circularly polarized 11.7 GHz satellite beacon transmitter aboard CTS, 35 months of attenuation, cross-polarization and rain-rate data were obtained in Austin, Texas. Data events are significantly more likely during April-September, than during October-March, except for ice-depolarization which predominates during the winter months. A time of day dependence of the events is also noted. The 10 dB fade level is exceeded for .03% during the thunderstorm months. Isolation with the same probability is 23 dB.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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I. INTRODUCTION

The nominally right hand circularly polarized 11.7 GHz beacon transmitter on the Dominion of Canada's Communication Technology Satellite (CTS) has been monitored in Austin, Texas for the purpose of collecting long-term statistical data on attenuation and cross-polarization effects. The observations began June 16, 1976 and ended June 30, 1979. During this time the beacon was in continuous operation, except for the first eclipse deactivation from August 31, 1976 to October 17, 1976 and for subsequent brief daily shut-downs (up to about 90 minutes), whenever the satellite was without solar power input. A total of 1062 days of data were obtained.

The receiver continuously recorded the power-levels in the co- and cross-polarized channel and the rain rate. Previously issued reports presented the results of this experiment for the period 12 June 1976 to 30 August 1976[1], 18 October 1976 to 31 January 1978[2] and 1 February 1978 to 31 January 1979[3]. This report contains the results of the analysis performed on all the data.

II. RECEIVER DESCRIPTION

A detailed description of the receiver has been given previously (1). Only the most pertinent characteristics of the receiver and data collection system are repeated in Table II-1.

TABLE II-1

Dual Polarization CTS Beacon Receiver

Location:	30°23'24"N Latitude 97°55'48"W Longitude 244m Altitude
Antenna:	3m parabola, prime focus feed, f/D = .375, program pointing to .02°, beamwidth .5°, elevation ≈ 50°
Feed:	turnstile polarizer
Polarization:	RHC, LHC (nominally) matched by adjusting for minimum power in cross-polar channel during clear air propagation
Isolation:	better than 45 dB with optimum pointing
Fade margin:	30 dB for co-polarized (RHC) channel 45 dB for cross-polarized (LHC) channel
Calibration:	Precision attenuated 11.7 GHz signals injected into front end
Output:	logarithmic amplitudes, recorded on strip chart, computer digitized at 5 samples per minute

III. METEOROLOGICAL DATA

The weather parameters of interest to this experiment are the number of days with thunderstorms and the total precipitation. Table III-1 gives the long term means and the actually observed values for the number of thunderstorm days and the accumulated rain in mm. Besides showing the overall statistics, the "winter" months October through March and "summer" months April through September have been separated.

This was done because, as the annual summary of the Austin local climatological data states, "precipitation is fairly evenly distributed throughout the year, with heaviest amounts occuring in late spring. A secondary rainfall peak occurs in September. Precipitation from April through September usually results from thunderstorms, with fairly large amounts falling within short periods of time. While thunderstorms and heavy rains have occurred in all months of the year, most of the winter precipitation occurs as light rain."

The table shows close to average weather during the winter months and somewhat drier weather with less thunderstorms than expected for the summer months.

TABLE III-1

Weather Data for Austin, Texas for Reporting Period

Period	# of thunderstorm days/ month		mm precipitation/month	
	mean	measured	mean	measured
Oct-Mar	2.00	2.01	61.98	59.84
Apr-Sep	4.83	3.88	78.99	70.85
all	3.42	2.95	70.49	65.35

IV. SUMMARY OF THE MEASUREMENTS

The quantities recorded on stripchart were (1) the signal level in the co-polarized channel, (2) the signal level in the cross-polarized channel and (3) the time intervals needed for the accumulation of .254 mm

of precipiation by a tipping bucket rain gauge. All charts were inspected for data events, when either the attenuation exceeded 1 dB or the isolation was less than 35 dB or the rain rate exceeded 5 mm/hr. The selected data event records were computer-digitized. For each sample period (12 seconds) the values of the attenuation (dB below clear-air-level), isolation (ratio of co-power to cross-power in dB), and average rainrate were calculated and stored in groups of 30 minutes of data. These groups were then used for the analysis of the data. The calculations used the calibrations performed at approximately weekly intervals, depending upon the weather. The calibrations were made by injecting a precision attenuated 11.7 GHz signal of known level into the front ends of the receiver. The "clear weather" reference level of 0 dB excess attenuation over oxygen and water vapor losses was established by noting the attenuator setting which produced the same output as the satellite beacon during clear and dry weather conditions. During the 35 months of operation of the receivers a variety of random failures and many regular beacon shutdowns for eclipse periods prevented the making of a gapless record for the measurements. A review of the few periods when gaps coincided with data events, as judged by the available measurements, by weather data or by propagation data obtained in the vicinity at other frequencies, led to the conclusions that the "lost data" do not impact the results obtained significantly.

A variety of data event types was observed. Cumulus clouds forming

in the warm and moist air from the Gulf of Mexico produced fluctuations in the co-polarized channel of up to about ± 1 dB. They did not introduce polarization effects.

Rainshowers without thunderstorms resulted in data events with the highest similarity in the chart outputs of the co- and cross-polarized channels. With thunderstorms and therefore presumably ice present in the propagation path impulse and step changes in the isolation were observed. Many, but not all, of the rapid changes could be visually correlated with lightning discharges.

Finally, usually during the winter season and typically associated with cold fronts moving through, ice depolarization events were observed. These were not accompanied by significant attenuation. The cross-polarized signal showed changes from fast (seconds) to slow (tens of minutes). On occasion, when the residual level of cross-polarization was above the measurement threshold due to pointing misalignment, ice depolarization events reduced the cross-power by changing the polarization of the incoming wave to produce a better match with the antenna.

The data analysis was performed for the "winter" months October through March, and the "summer" months April through September in addition to the analysis on the complete set and the periods June 76 - May 77, June 77 - May 78 and June 78 - June 79.

Tables IV-1 through IV-3 give the attenuation, isolation and rainrate distributions. From these tables Figures IV-1 through IV-6 were drawn,

TABLE IV-1

ATTENUATION DISTRIBUTION - UNIV OF TEXAS - JUN 76 TO JUN 79
CTS/11.7GHZ/RHC POLARIZATION/50 DEG. ELEVATION

Attenuation exceeded (dB)	Oct-Mar (Minutes)	Apr-Sep (Minutes)	All data (Minutes)
1	2702	3003	5705
2	885	1360	2245
3	460	890	1350
4	299	691	990
5	193	556	749
6	120	454	574
7	83	389	472
8	48	334	382
9	28	277	305
10	22	237	259
11	17	208	225
12	14	179	193
13	10	154	164
14	7	136	143
15	4	124	128
16	4	114	118
17	3	100	103
18	3	84	87
19	3	73	76
20	2	66	68
21	1	49	50
22	0	44	44
23	0	41	41
24	0	39	39
25	0	37	37
26	0	35	35
27	0	34	34
28	0	33	33
29	0	30	30
30	0	28	28

TABLE IV-2

ISOLATION DISTRIBUTION - UNIV OF TEXAS - JUN 76 TO JUN 79
CTS/11.7GHZ/RHC POLARIZATION/50 DEG. ELEVATION

Isolation less than (dB)	Oct-Mar (Minutes)	Apr-Sep (Minutes)	All data (Minutes)
35	5040	3486	8526
34	4061	2930	6991
33	3149	2399	5548
32	2378	1992	4371
31	1787	1655	3442
30	1352	1391	2742
29	1049	1103	2151
28	747	870	1618
27	458	709	1167
26	295	573	868
25	179	439	618
24	104	320	424
23	59	239	298
22	36	191	227
21	25	149	174
20	16	117	134
19	8	83	91
18	5	60	65
17	2	37	39
16	1	25	26
15	1	11	12
14	1	3	4
13	0	1	1

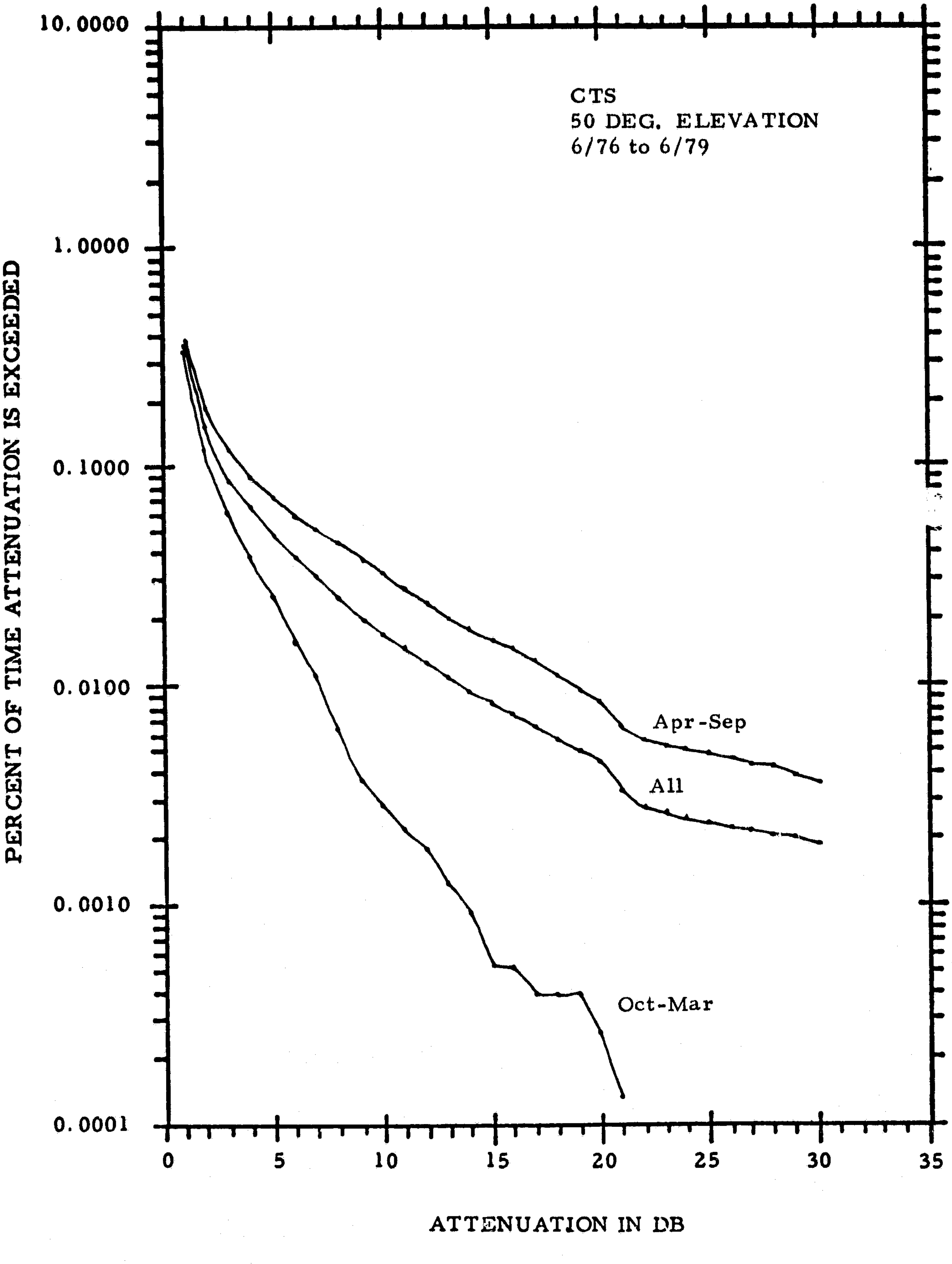
TABLE IV-3

RAIN RATE DISTRIBUTION - UNIV OF TEXAS - JUN 76 TO JUN 79

Rain Rate exceeded (mm/hr)	Oct-Mar (Minutes)	Apr-Sep (Minutes)	All data (Minutes)
5	1559	2221	3780
10	733	1233	1966
15	488	867	1355
20	320	666	986
25	225	504	729
30	153	396	549
35	103	309	412
40	77	254	331
45	53	198	251
50	39	166	205
55	27	128	155
60	23	109	132
65	19	88	107
70	13	71	84
75	12	63	75
80	9	53	62
85	7	43	50
90	5	36	41
95	4	30	34
100	3	23	26
105	2	20	22
110	2	17	19
115	1	13	14
120	1	9	10
125	1	7	8
130	0	5	5
135	0	4	4
140	0	3	3
145	0	3	3
150	0	2	2

FIGURE IV-1

11.7 GHZ ATTENUATION DISTRIBUTION
AUSTIN, TEXAS



11.7 GHZ ISOLATION DISTRIBUTION
AUSTIN, TEXAS

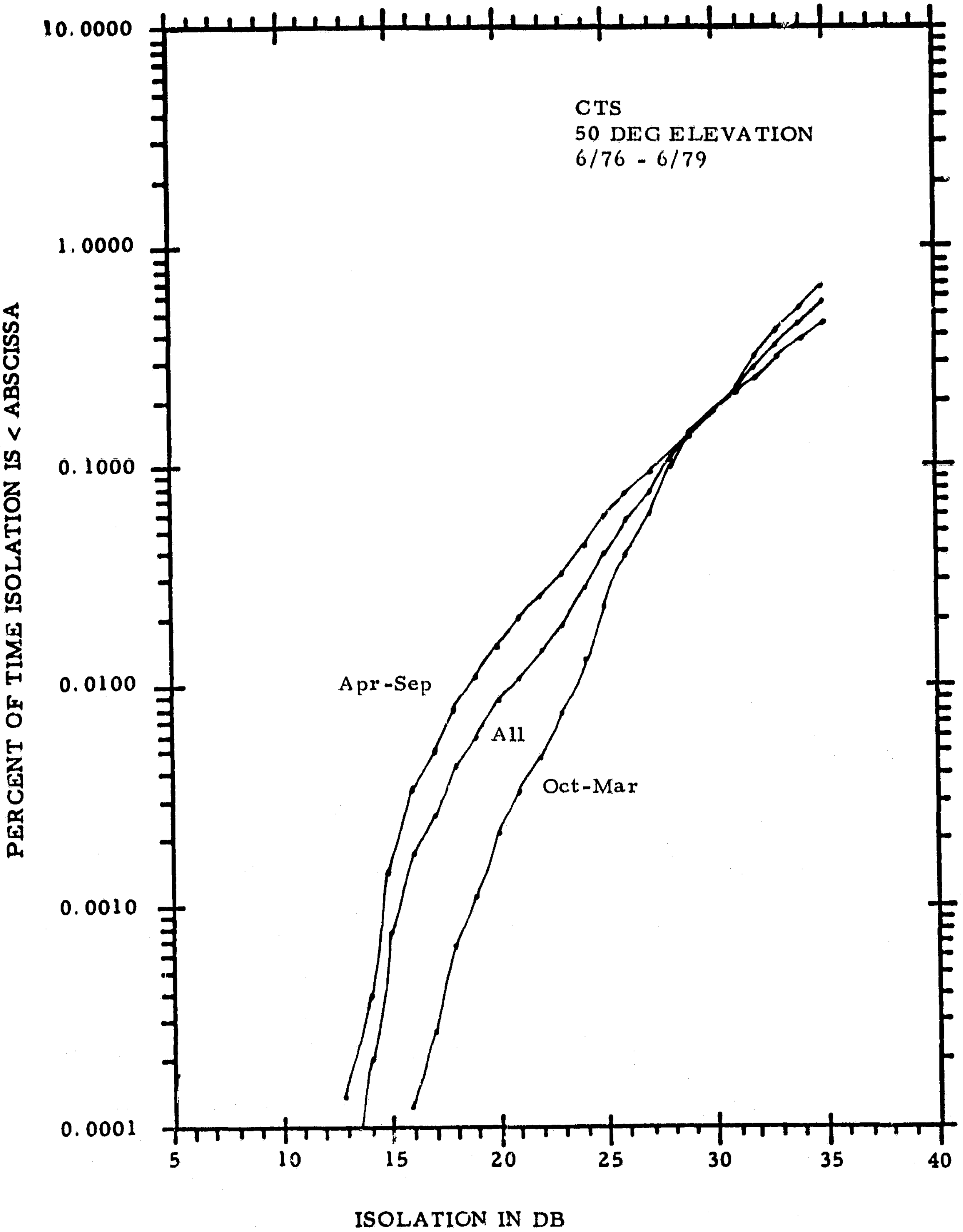


FIGURE IV-3

RAIN RATE DISTRIBUTION
AUSTIN, TEXAS

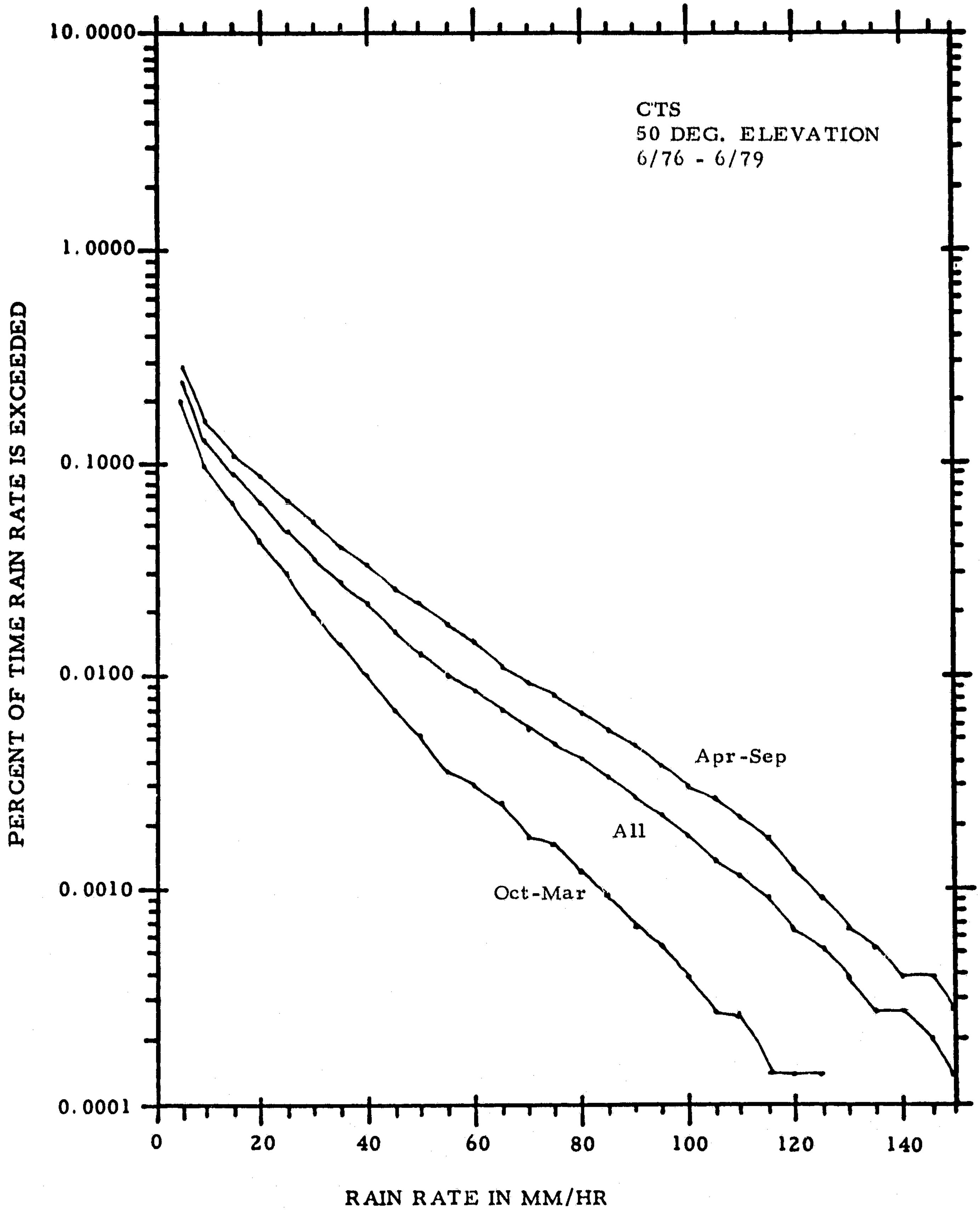


FIGURE IV-4

11.7 GHZ ATTENUATION DISTRIBUTION
AUSTIN, TEXAS

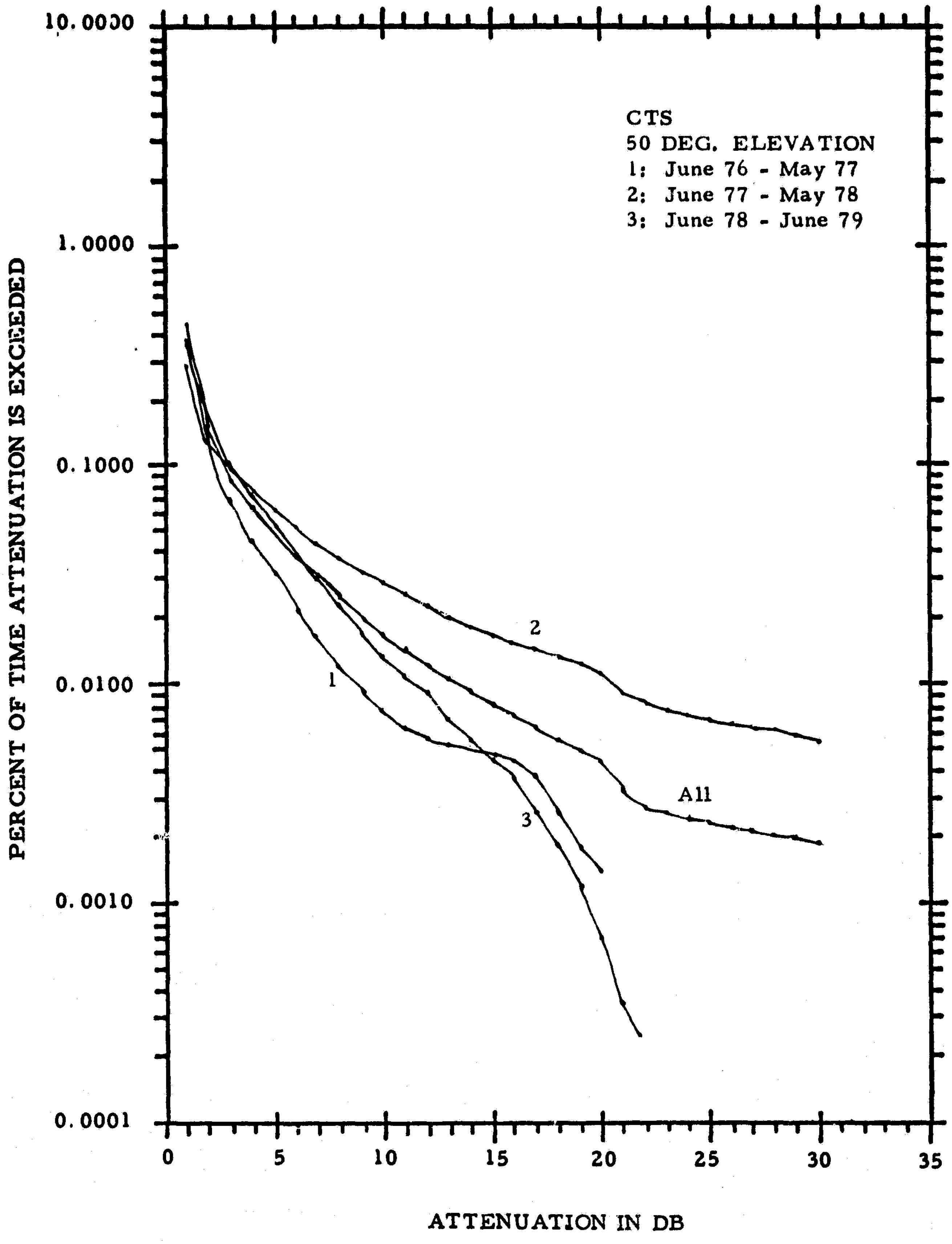


FIGURE IV-5

11.7 GHZ ISOLATION DISTRIBUTION
AUSTIN, TEXAS

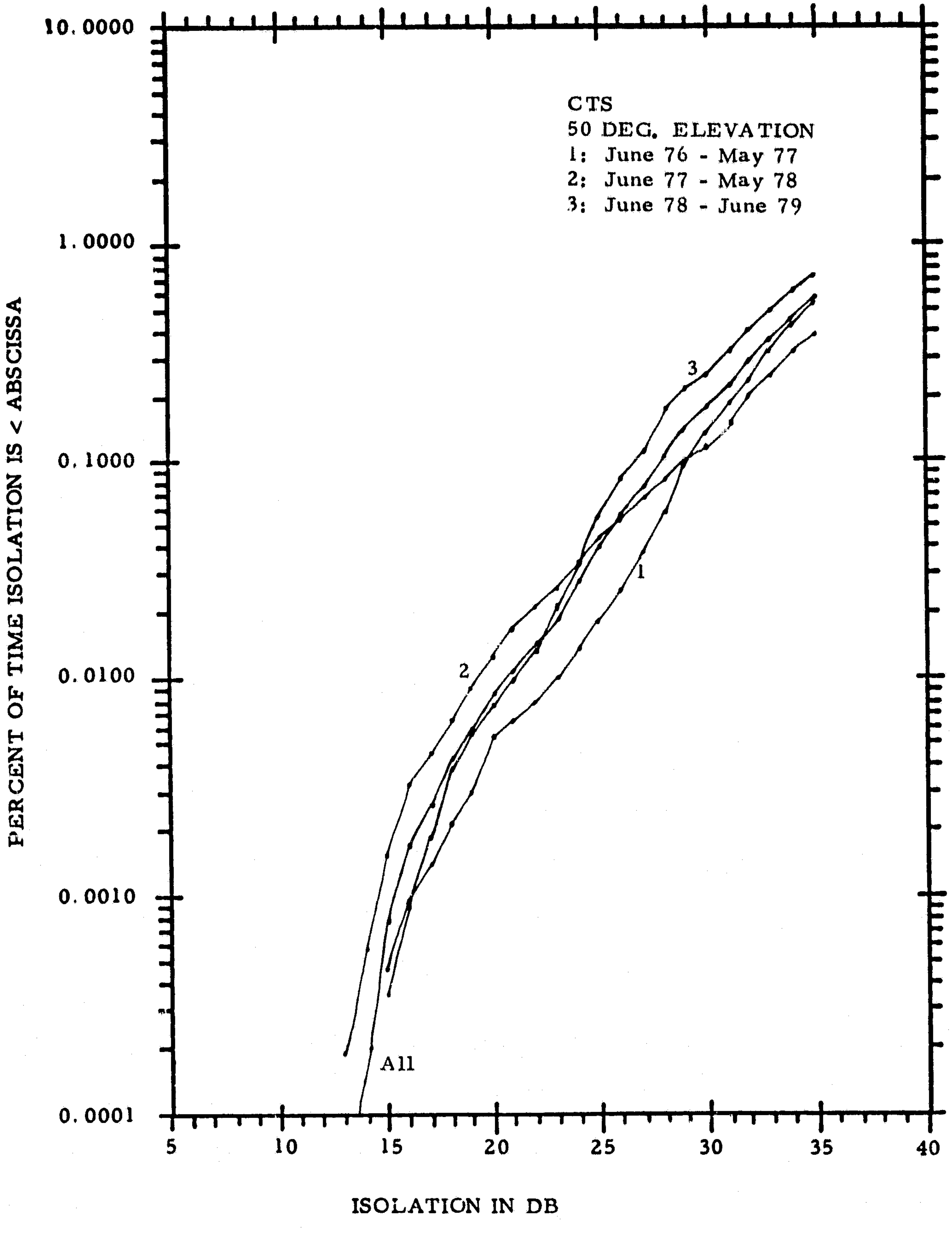
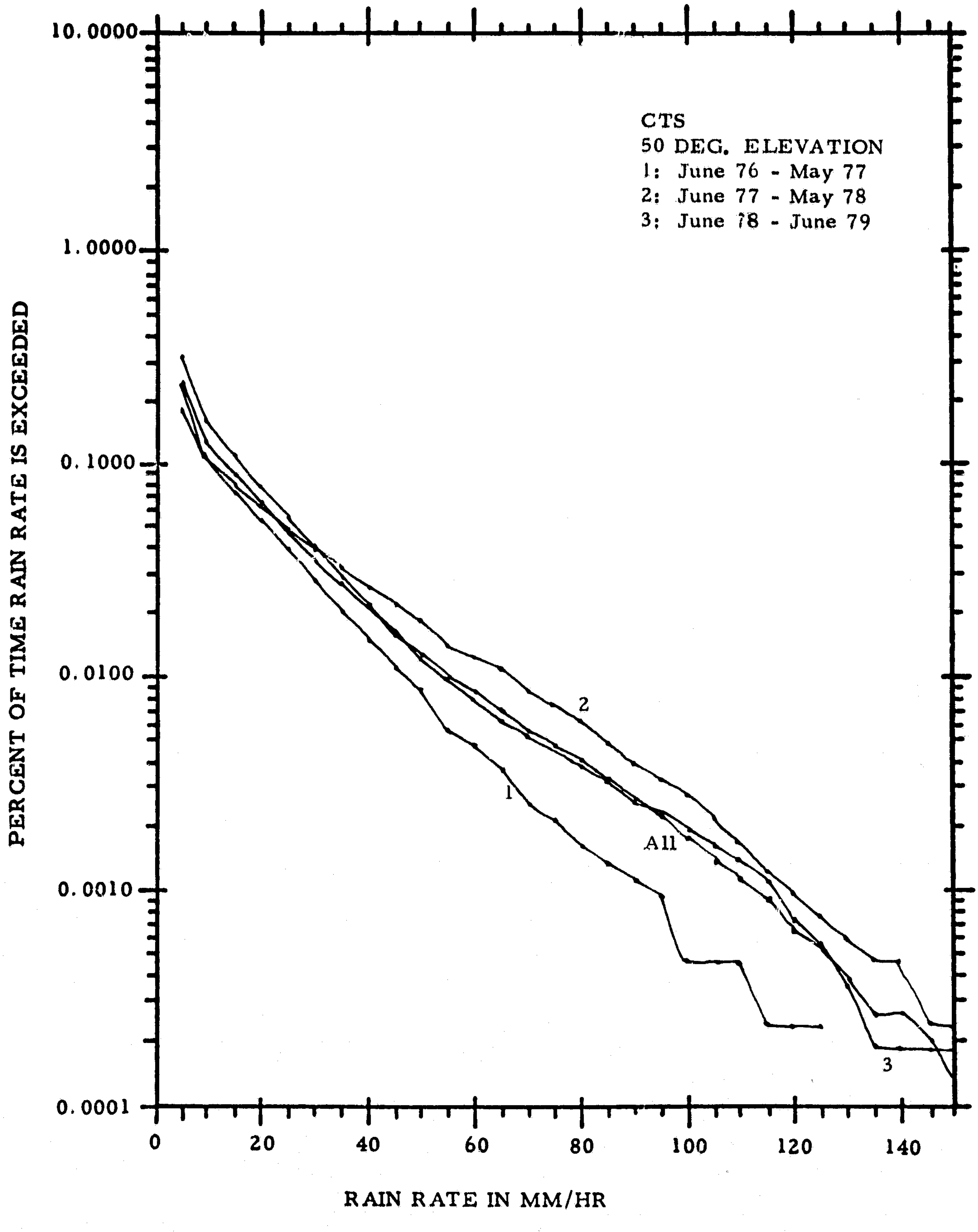


FIGURE IV-6

RAIN RATE DISTRIBUTION
AUSTIN, TEXAS



showing the percentage of time the attenuation exceeded, the isolation was less than and the rain rate exceeded the respective abscissa. Of the total period of observation (1,529,280 minutes), 761,760 were during "winter" and 767,520 during "summer" months.

The attenuation exceedence plot IV-1 shows the essentially bimodal nature of fade events as indicated by the climatological data. The 10 dB fade level was exceeded for 2.9×10^{-3} percent of the time during winter. During the summer this probability increased by a factor of 10 to 3.1×10^{-2}.

The isolation distribution plot IV-2 shows a similar, if somewhat less severe, seasonal difference for the lower isolation values. At about 30 dB isolation there is a crossover however. During the winter months the probability for isolation loss in the above 30 dB range is actually larger than during the summer months. This can be attributed to ice depolarization events which occur primarily during the winter season. In Figure IV-3 the rain rate exceedence plot shows that rainrates are lighter for the winter than for the summer months. From the climatological description one might expect a higher probability for low rainrates during the winter months, in order to keep the fairly even distribution of the rain amount. This crossover is not apparent in the graph, however. It would probably occur at below 5 mm/hr and is therefore not resolved. The instantaneous relationship between isolation and attenuation has been found to vary widely.[2] By comparing equal-probability values of

attenuation and isolation, a statistical connection between the two can be derived, however.

A least squared error fit using attenuation values up to 20 dB for the three approximately 12-month observation periods was made, resulting in:

June 76 - May 77: Isolation = 34.2 - 12.4 log A (r^2 = .98)

June 77 - May 78: Isolation = 34.0 - 10.8 log A (r^2 = 1.0)

June 78 - June 79: Isolation = 33.0 - 12.2 log A (r^2 = .96).

For all the data the fit resulted in

$$\text{Isolation} = 33.6 - 11.5 \log A$$

with a coefficient of determination r^2 = .99. These equal probability pairs and the fitted curve are shown in Fig. IV-7. Also plotted are 3 curves which give information about the distribution of the instantaneous attenuation-isolation pairs. For instance the three values at 5 dB attenuation (33, 29 and 24) mean that for the data samples with attenuation A given by

$$4 < A \leq 5 \text{ dB}$$

90% of the data collected had CPI greater than 24 dB, 50% of the data had CPI greater than 29 dB and 10% had CPI greater than 33 dB. The curves are reasonably smooth up to 20 dB attenuation. For values greater than that the scarcity of the number of samples in each interval introduces greater scatter. The equal probability isolation is smaller than the median isolation for $A < 10$ dB and greater for 10 dB $< A < 20$ dB. This indicates a change in the density function of CPI for each given A.

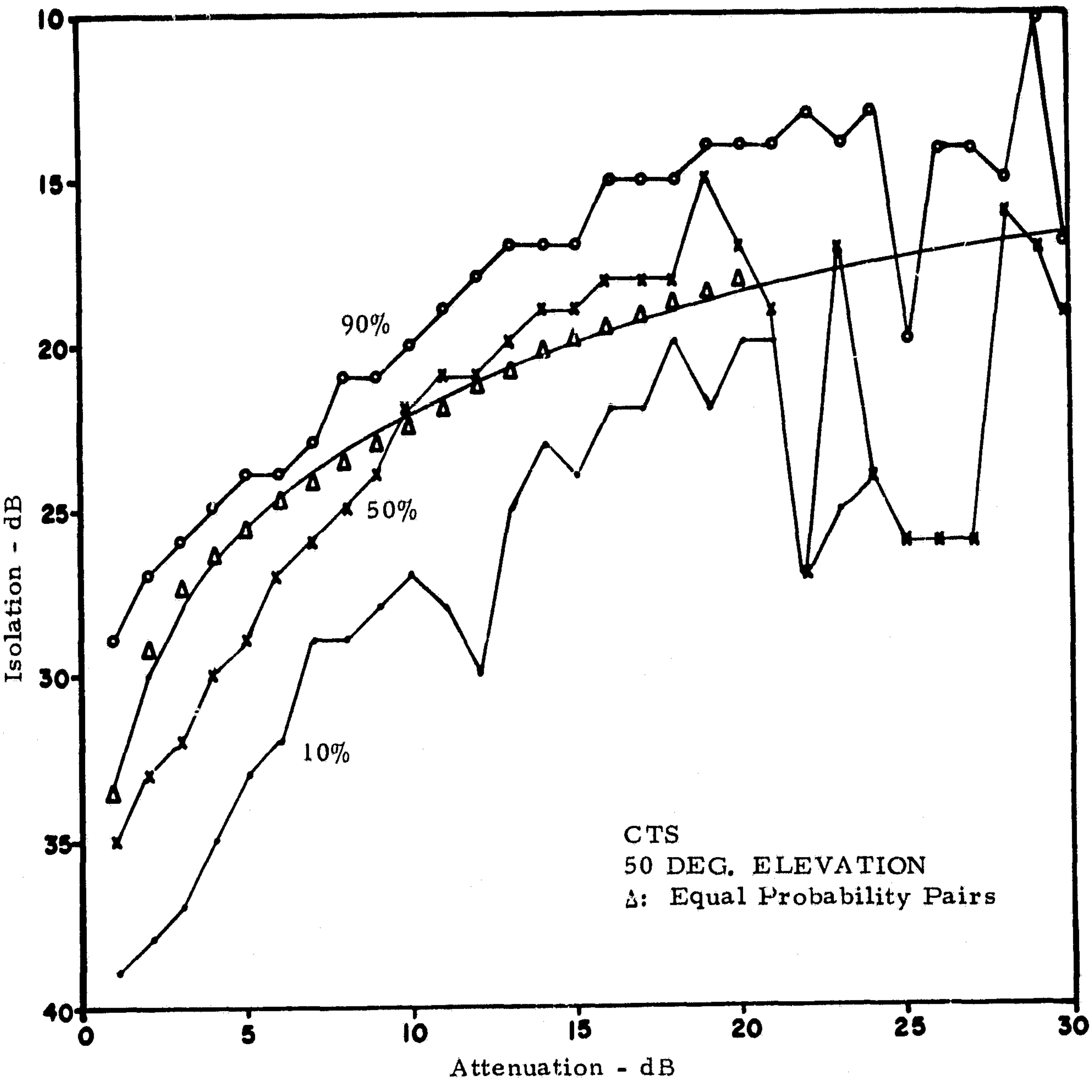


FIGURE IV-7: Isolation vs Attenuation

Figure IV-8 shows the distribution function of the measured isolations, given that the attenuation is less or equal than 1 and 2 dB. The curve for 1 dB attenuation has a lesser slope because the isolation values are spread out over a greater range. This is due to ice-depolarization.

Equal probability pairs for attenuation and rainrate were used to derive the statistical relationship between the two. A power curve fit resulted in

$$A = .14\ R^{1.13}$$

where $r^2 = .99$, where A is given in dB and R in mm/hr. Separating the elevation angle dependence in this formula results in

$$A = \frac{.11}{\sin 50°}\ R^{1.13}.$$

This relationship is shown in Fig. IV-9.

For the three periods June 76 - May 77, June 77 - May 78 and June 78 - June 79 the curve fits resulted in $A = .12\ R^{1.15}$, $A = .18\ R^{1.12}$ and $A = .23\ R^{.96}$. The variation in this relationship is understandably large from year to year, considering that the rainrates were measured with one tipping bucket gauge at a point and the attenuation occurs along a slant path. Any modeling on this relationship should probably take the orientation of the slant path with regard to the predominant rain storm movements into account.

Given in Table IV-4 are the distribution data, separated into four six-four intervals for winter, summer and all data. It is seen that the

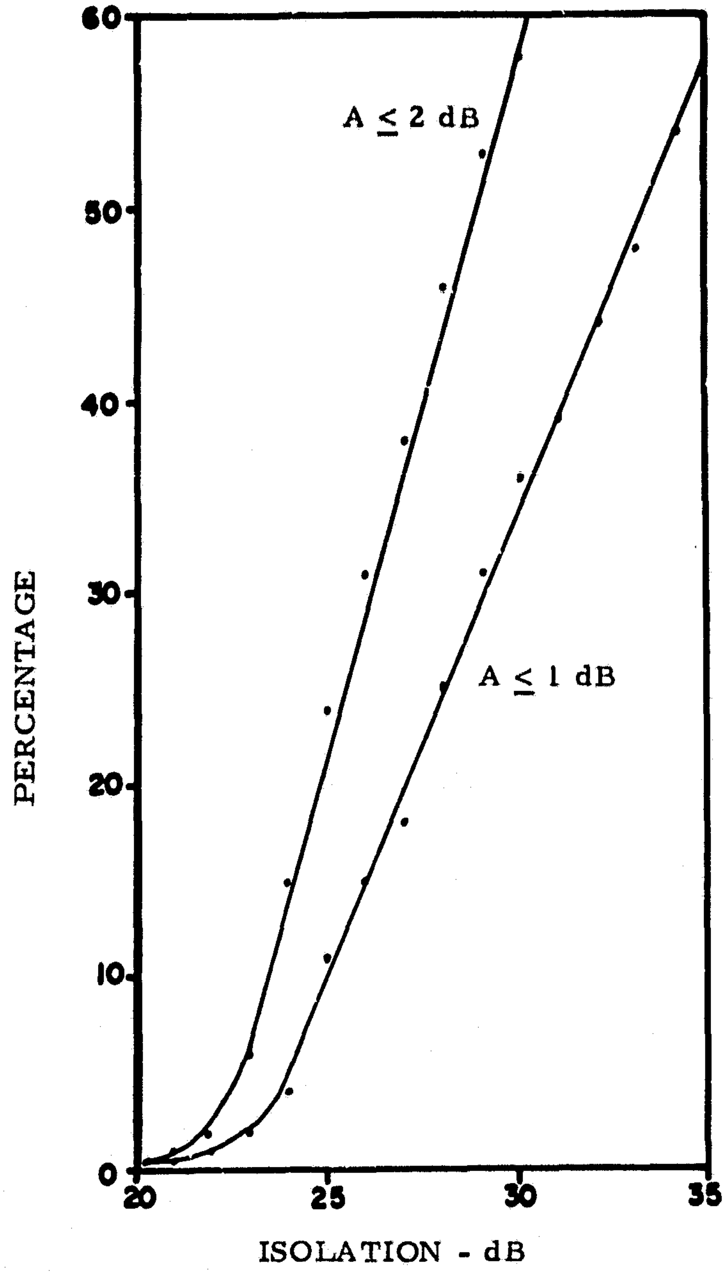


FIGURE IV-8: Isolation Distribution

$$\text{Percentage} = 100 \times \frac{\text{Time that isolation} < x, \text{ given } A \leq y\text{dB}}{\text{Time that isolation} \leq x}$$

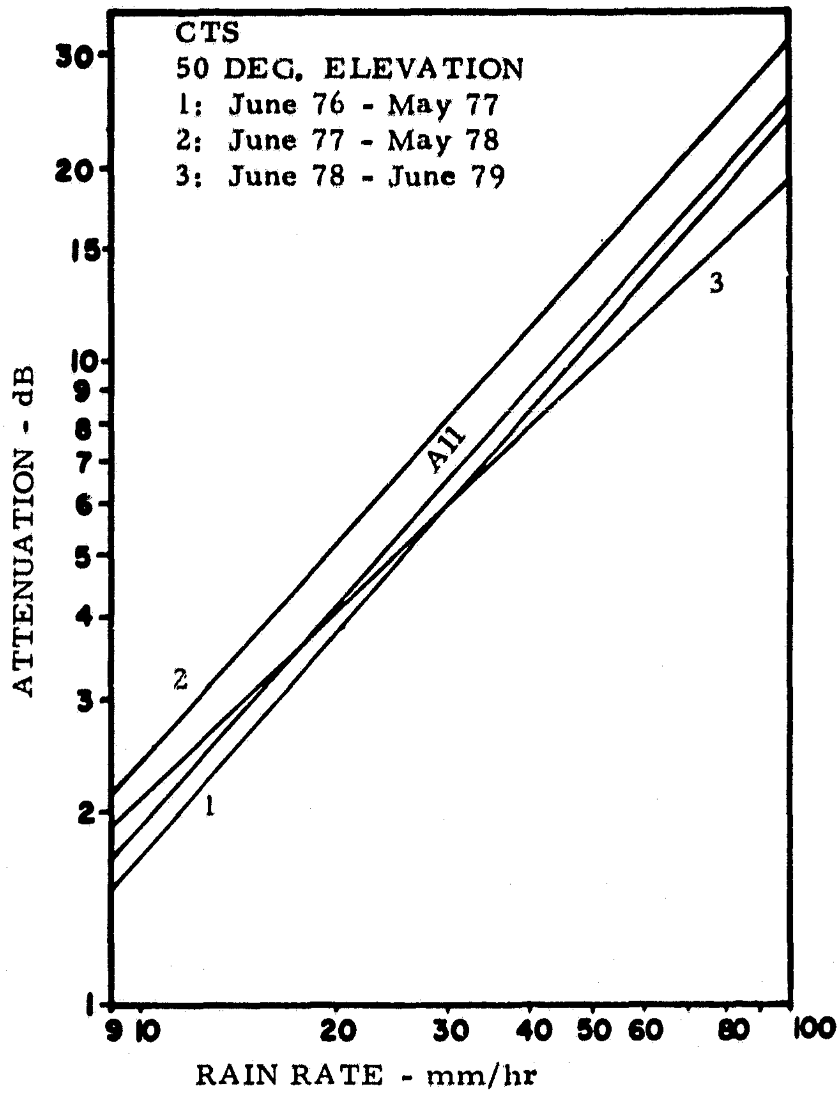


FIGURE IV-9: Equal probability fits

for attenuation vs rainrate pairs

TABLE IV-4

TIME OF DAY DATA - UNIV OF TEXAS - JUN 76 TO JUN 79
CTS/11.7GHZ/RHC POLARIZATION/50 DEG. ELEVATION

Time of day (GMT)		Minutes the attenuation exceeded 3	6	10	20	25	30 dB
0-6	W	53	18	5	1	0	0
	S	292	154	79	40	36	25
	A	345	172	84	41	36	25
6-12	W	87	21	3	0	0	0
	S	117	43	27	1	0	0
	A	204	64	30	1	0	0
12-18	W	261	65	10	1	0	0
	S	86	30	17	3	0	0
	A	347	95	27	4	0	0
18-24	W	58	16	4	0	0	0
	S	395	228	115	22	7	3
	A	453	244	119	22	7	3

		Minutes the isolation was less than 35	30	25	20	15 dB
0-6	W	1441	392	36	1	0
	S	1118	429	132	29	3
	A	2559	821	168	30	3
6-12	W	1657	536	49	4	0
	S	922	272	84	37	5
	A	2579	808	133	41	5
12-18	W	1433	318	69	9	1
	S	377	169	50	11	0
	A	1810	487	119	20	1
18-24	W	510	104	24	2	0
	S	1069	520	170	41	2
	A	1579	624	194	43	2

		Minutes the rain rate exceeded 5	25	50	75	100 mm/hr
0-6	W	380	39	6	2	1
	S	618	153	54	23	9
	A	998	192	60	25	10
6-12	W	296	59	10	2	0
	S	508	144	47	14	3
	A	804	203	57	16	3
12-18	W	608	83	21	8	2
	S	307	54	19	9	4
	A	915	137	40	17	6
18-24	W	273	41	2	0	0
	S	787	209	46	17	7
	A	1060	250	48	17	7

W=Oct-Mar; S=Apr-Sep; A=All data

events are not uniformly distributed, but depend upon the time of day. The data for fades of 10 dB, isolation of 20 dB and rainrate of 50 mm/hr have been drawn in Fig. IV-10. On a linear scale each bar graph shows the occurrence of these events during each 6 hour interval relative to their mean occurrence. For instance, during the winter months, it is about twice as likely for the events to happen between 12 and 18 hours GMT (6 am to 12 noon CST) than their mean predicts. It is interesting to note that there is a lack of correlation between the summer-afternoon attenuation peak and the corresponding point rainrate. The summer-data, because of their greater weight, dominate the overall statistics.

Finally, the data events have been analyzed for their duration. Table IV-5 presents these results. With few exceptions, the number of events decreases with severity and duration. The rain rate durations for 5 mm/hr are not properly resolved by the rain gauge, since it takes about 3 minutes at that rate between tips.

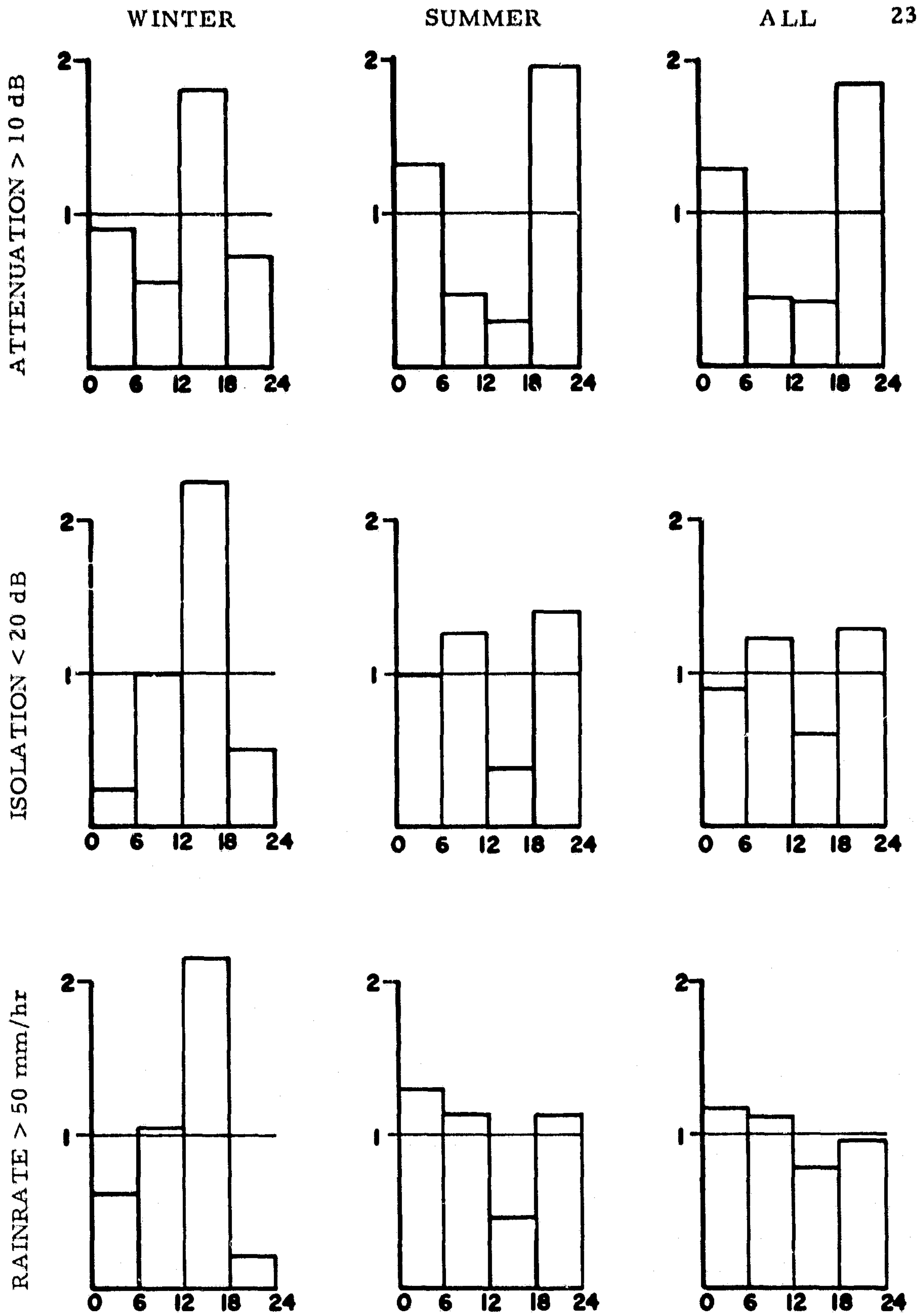


FIGURE IV-10: Time of day dependent of data events

TABLE IV-5

DURATION DATA - UNIV OF TEXAS - JUN 76 TO JUN 79
CTS/11.7GHZ/RHC POLARIZATION/50 DEG. ELEVATION

Duration interval (Min)		No. of events when attenuation exceeded 3	6	10	20	25	30 dB
0	1	88	60	23	27	11	3
1	2	39	20	6	2	1	0
2	4	37	25	15	4	1	0
4	8	41	17	11	1	0	0
8	16	27	17	7	1	0	2
16	32	18	5	1	0	0	0
32	64	2	0	0	0	0	0
64	UP	1	0	0	0	0	0

Duration interval (Min)		No. of events when isolation was less than 35	30	25	20	15 dB
0	1	873	529	198	34	20
1	2	242	138	55	14	3
2	4	165	108	24	9	0
4	8	171	70	25	4	0
8	16	109	39	12	4	0
16	32	74	22	3	0	0
32	64	32	10	1	0	0
64	UP	13	1	0	0	0

Duration interval (Min)		No. of events when rain rate exceeded 5	25	50	75	100	125 mm/hr
0	1	8	158	209	136	85	32
1	2	43	63	24	7	2	0
2	4	115	64	9	3	0	0
4	8	99	26	8	2	0	0
8	16	86	16	2	0	0	0
16	32	47	2	0	0	0	0
32	64	8	0	0	0	0	0
64	UP	4	0	0	0	0	0

V. CONCLUSIONS

Attenuation, cross-polarization and rainrate data have been presented for a 35 month period. A significant seasonal variation in the data is noted, with events from April to September being more severe. This is due to the fact that rain during these months falls in intensive showers. The probability of data events occurring has also been found to depend on the time of day. Assuming a fade margin of 10 dB for an operational frequency diversity system employing circular polarizations would lead to a 23 dB isolation requirement. Since higher isolation values are required, the system would be isolation limited.

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